In response to the public consultation on Clean Aviation Partnership:

A short comment on ultra-efficient gas turbines and sustainable aviation fuels

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SUMMARY

This two-page comment on the Clean Aviation SRIA, contains output from two Horizon 2020 projects, ULTIMATE (ultra-efficient engines) and ENABLEH2 (hydrogen aircraft). The submitter was coordinator of the ULTIMATE project and has a senior role in Chalmers Universities major contributions to ENABLEH2. The submitter has also been responsible for collecting strategic inputs from Chalmers University of Technology. Some output from efforts on road-mapping conducted together with leading aero engine manufacturers is also supporting this comment.

This comment concentrates on giving comments on the two key thrusts "3. Ultra-efficient Aircraft and Gas Turbines" and "4. Sustainable Aviation Fuels enabled Aircraft". However, for all four thrust areas, it is noted that as aircraft design complexity increases the need for dynamic modelling, energy management and optimal control increases.

Comment on Thrust area 3: ULTRA-EFFICIENT AIRCRAFT AND GAS TURBINES

It is well-known that state-of-the-art propulsion systems have efficiencies somewhat higher than 40% (for longer range applications). Losses recomputed to lost work for a 2015 cycle are shown in Figure 1. In ULTIMATE a large number of combinations of technologies were explored to identify cycles (up to TRL 2 analysis), with potential to have a major effect on the fuel efficiency of the aircraft. In short the findings are,

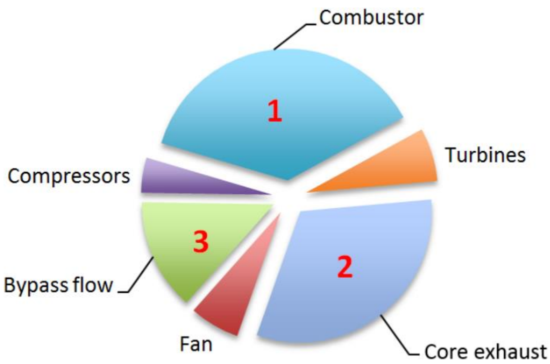

Figure 1: lost work in a modern turbofan

1. "**Combustor**" explored several concepts for **pressure rise combustion**. In particular in combination with intercooling, these cycles consistently showed **double digit** fuel burn reduction even when compared to ultra-efficient anticipated year 2050 conventional cycles!
2. Reducing "**Core exhaust**" losses by recovering heat was shown to be possible but closer analysis taking installation effects into accounts showed that the potential was modest.
3. **"Bypass flow"**, concepts are already being addressed well through the introduction of geared fan concepts and optionally open rotor aircraft. Strategic research focus in this area is viewed to have been strong in previous Clean Sky efforts.

It is argued that no current technology area is currently promising to deliver such a huge step in energy efficiency as integrating **pressure rise combustion**. Due to the energy density of liquid fuels, it is viewed that these will be key for long range aircraft in the foreseeable future. Higher fuel costs must be accepted to limit CO_2 emissions and allow for sustainable fuels. Then, long term radical concepts need targeted research; otherwise this opportunity may else be missed out on. To push this technology area technology maturation projects ranging from TRL3-TRL5 are urgently needed. Key enabling technologies are heat management and intercooling, controls and optimization of solutions, experimental validation of NO_x emissions and integration with hybrid electric concepts.

Comment on thrust area 4: SUSTAINABLE AVIATION FUELS ENABLED AIRCRAFT

For use of hydrogen two tracks are now emerging;

1. more frequently it is anticipated that future aircraft concepts fueled by hydrogen will use fuel cell technology.
2. **direct combustion of hydrogen in a conventional type aero engine cycle** is often overlooked despite that
    a. hydrogen combustion offers thermal efficiencies beyond 50%,
    b. it avoids the exceptional challenges with fuel cell compactness and their loss of efficiency at high loads
    c. it greatly simplifies designing combustors for ultra-low NO_x.

Contrails formation and water vapour in the atmosphere have been brought forward as arguments against direct combustion. However, this effect is likely to be substantially limited by hydrogen being a clean fuel that reduces soot particles in combustion. It has recently been understood that this limits contrail formation substantially. There is also great opportunity to drastically reduce contrail emissions by flight avoidance schemes. A smaller part of all flights give rise to a large part of the contrail formation, and for these flights' avoidance schemes can be developed with quite small decrease in energy efficiency.

Another opportunity for Europe is that power generation companies now push very hard for hydrogen combustion. This should allow cross cutting research to be performed and making results useful for both aviation and power generation. Low-NO_x hydrogen combustors could make an important contribution to the transformation to new energy systems.

Key technologies that need maturation, in the range TRL3-5, are elements of cryogenic fuel handling and integration, technologies to maximize vehicle efficiency by heat management, low-emissions combustors such as Micromix combustors, as well as activities focusing on ensuring safe handling of hydrogen. In addition, cryogenic fuels provide excellent synergy with electrification and the use of superconductivity.

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